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FINAL TECHNICAL REPORT

NASA Grant NSG 5360

"Ultraviolet Observations of M32, A Cosmological Comparison"

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Final Report to NASA, on Completion of Grant NSG 5360
"Ultraviolet Observations of M32, A Cosmological Comparison"

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June, 1980

Technical Report:

Spinrad and graduate student Gustavo Bruzual obtained spectra of four galaxies (including M32) and numerous cool, bright stars with the IUE satellite in May/June 1979. The objective of this observational research was to compare the average UV spectrum of nearby E/So/Sb galaxies (systems with little or no current star-formation near their centers) with distant, red-shifted galaxies, observed with large telescopes on the ground. The differences are a measure of galactic evolution over the long (∿ 6-10 billion-year) look-back times to redshifts of 0.5-1.0.

The details of the IUE galaxy data reduction, conclusions from the integrated spectra of nearby E galaxies, and the (brief) comparison with distant galaxy spectral energy distribution are found in a paper by Bruzual and Spinrad (1980), just given at the May 1980 Goddard conference on results from IUE ["The Universe at Ultraviolet Wave Length: The First Two Years of IUE."], and here appended.

THE ULTRAVIOLET SPECTRA OF EARLY TYPE GALAXIES*

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ABSTRACT

The average spectral energy distribution for a sample of bright elliptical galaxies is presented in the range λλ 2000 to 3200 A. Spectral synthesis indicates that elliptical galaxies are most likely older than 9 Gyrs. The ultraviolet flux is consistent with a population of red horizontal branch stars, as those present in metal-rich globular clusters. Data for distant ($z \sim 1$) first ranked cluster galaxies show indications of spectral evolution.

INTRODUCTION

Detailed knowledge of the ultraviolet spectra (λλ 2000-3200A) of early type galaxies is important for at least three reasons. First, it may provide clues about the presence of a hot stellar population which does not contribute appreciably at optical wavelengths. Second, spectral features identified in the spectra of nearby galaxies can be used as redshift indicators for distant galaxies (up to $z \sim 1$). And, third, combining this information with our notions of stellar evolution, some conclusions about the spectral evolution of galaxies can be derived. In particular, the stellar population present in first ranked galaxies in distant clusters can be compared with that expected for galaxies of different morphological types at the corresponding age, and, hence, the correctness of the assumption of similarity of all first ranked cluster galaxies can be tested.

OBSERVATIONS

Low resolution IUE spectra with moderate signal-to-noise ratio in the range from 2000 to 3200 A are now available for several early type stellar systems. Table I gives galaxy identification and morphological type, exposure time and IUE observer for the sample used in this paper. Figure 1 shows the average spectral energy distribution, where each galaxy spectrum has been normalized at 2900 A and weighted according to the exposure time.

The most conspicuous spectral features that can be seen in this spectrum are the Mg I (2852) and Mg II (2799) absorption

lines and the spectral discontinuities at 2420, 2640, and 2900 A, which result from the blends of many metallic lines. This spectrum is characteristic of a metal-rich stellar population, as can be seen from the IUE spectra of globular clusters (ref. 3). These features are prominent in spectral types A7 to F8 (ref. 4). No emission lines have been detected in this spectral range. The high frequency structure for λ < 2300 and λ > 3200 A is due to the low signal-to-noise ratio of the individual spectra at their edges, and does not represent reproducible spectral features. This has been checked by comparison with a ground based spectrum of M32 of high signal-to-noise ratio, down to λ 3200 A. The apparent sharp absorption features at $\lambda\lambda$ 2400, 2580, and 3100 A are due to reseau marks in the IUE camera.

INTERPRETATION

The quality of the present data is high enough to allow an interpretation of the spectrum in terms of the stellar population present in elliptical galaxies. As part of a separate investigation (refs. 5 and 6), evolutionary models for galaxy populations and spectra have been constructed. Elliptical galaxies are well represented by a model in which initial star formation takes place at a constant rate for a time interval of 1 Gyr, with an initial mass function similar to that observed in the solar neighborhood (x=1.35), and is zero afterwards. Evolutionary tracks for solar composition from Ciardullo and Demarque (ref. 7) are used to follow the subsequent evolution of the stellar population. The observed luminosity function for giants in the solar vicinity, as derived by Tinsley and Gunn (ref. 8), is used to complete the evolutionary tracks onto the giant branch. Standard stellar spectra for solar metallicity are used to construct the resulting galaxy spectrum with a resolution of 50 A in the optical region. In the ultraviolet, OAO-2 (ref. 4) spectra for stellar types earlier than G5, and IUE spectra obtained by the authors for late type giants, complete the spectra with a resolution of 10 A to 2000 A.

The following results have been derived from these models.

(a) In the region from 2000 to 4000 A the observed spectra are well reproduced by the model at an age of 5 Gyr. However, this model has B-V = 0.83, which is about 0.15 magnitude bluer than a typical giant elliptical. In addition, this young age implies formation redshifts for $q_o = 0$ of 0.34 (H_o = 50) or 1.04 (H_o = 100) which seem much too low for current views of massive galaxy formation. The predicted B-V at z = 0.46 is 1.26 (H_o = 100). This is too blue for the observed color of 1.4 (refs. 9 and 10). For a different interpretation, see ref. 11.

(b) In the region from 5000 to 8000 A, the observed spectrum is not reproduced until an age of 8 to 9 Gyr. However, by this time, the model is deficient in ultraviolet light. We have interpreted this deficiency as due to the lack of horizontal branch

stars in our model. To test this hypothesis we have added some light to the models from stars in the range F0 to F8, which resemble well the spectra of metal-rich globular clusters (ref. 3). The fraction of this light added to the models is arbitrary and depends on the age assumed for the galaxies. Table II shows the fraction of light inside the V-band for three different stellar groups at three possible galaxy ages. The fit to the observed spectrum from 2000 to 8000 A is equally good for any of these models. Thus, it does not seem possible to derive the typical age of the population on spectral grounds solely. Assumptions about the evolution of the horizontal branch population, together with observed spectra of galaxies at $z > 0.4$. may provide clues about the most plausible age. This is being explored in ref. 10.

(c) Even though some light from giant stars hotter than those commonly seen in the solar neighborhood is required to reproduce the galaxy data, these stars are not hotter than F0 (T=7200, B-V=0.30). In the HR diagram these stars fall to the right of the RR Lyrae instability strip, and thus are characteristic of a red horizontal branch (ref. 12). This is not surprising, given the similarity of the galaxy spectra and those of metal-rich globular clusters (ref. 3). The number of horizontal branch stars required to reproduce the spectra is equivalent to a few percent of the total number of stars in the red giant branch. This ratio is given in the last line of Table II. Most likely these stars are more conspicuous in the elliptical galaxies than in the solar neighborhood because of the intrinsic differences between both populations and the larger volume sampled in the case of the galaxies.

SPECTRAL EVOLUTION

Figure 2 shows the observed spectral energy distribution for E galaxies at $z=0$, 0.2, 0.5, and 1.1 in the rest frame of the galaxies (refs. 10 and 13). The galaxies at $z=0.5$ and 1.1 are bluer in the range $\lambda\lambda$ 2700 - 3800 A than the average nearby elliptical. Similarly, the amplitude of the 4000 A discontinuity is lower in the distant E galaxies than in nearby ones. This is expected from the normal evolution of the main sequence stars in these galaxies (ref. 5). The extent to which star formation could be taking place in these ellipticals at $z > 0.5$, as well as the relative importance of horizontal branch stars at the respective epoch is the subject of a separate investigation (ref. 10). Certainly, some luminous, red-color-selected E galaxies have had <u>no</u> active star formation over the last 5-7 Gyrs.

CONCLUSIONS

Our spectral synthesis models for the spectrum of elliptical galaxies in the range $\lambda\lambda$ 2000 to 8000 A imply that these systems are most likely older than 8-9 Gyr. The flux in the region from 2000 to 3200 A can be understood as being produced by stars in the red horizontal branch, similar to those observed in metal-

rich globular clusters. In this respect we disagree with the recent results of O'Connell (ref. 11). Spectra of distant elliptical galaxies show slight indications of evolution, consistent with our ideas about stellar evolution.

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TABLES

Table I. Galaxies observed with IUE

Galaxy**	Type	LWR exposure	Reference
M31 (nuc)	Sb	8.5 hrs	1,*
M32	dE2	5.5	*
NGC 3379	E1	7.0	2
NGC 4472	E2	10.5	*

* Data from authors.
** IUE aperture size was "large", an oval 10"x20" in dimension.

Table II. Fraction of Flux in the V-band

Model age (Gyr)	9	13	16
Turnoff	G5	G7	G9
[FO - F8] (HB)	0.05	0.09	0.13
Turnoff - M6V	0.44	0.37	0.34
Red Giants	0.51	0.54	0.53
N(HB)/N(RG)*	0.028	0.034	0.050

* Number ratio of horizontal branch to red giant stars.

FIGURE CAPTIONS

Figure 1. Average spectral energy distribution for galaxies listed in Table I. Each spectrum was normalized at 2900 A and then weighted according to the exposure time. (See text for details).

Figure 2. Observed spectral energy distribution for galaxies at z=0, 0.2, 0.5, and 1.1 in the rest frame of the galaxies. (See refs. 10 and 13 for details).

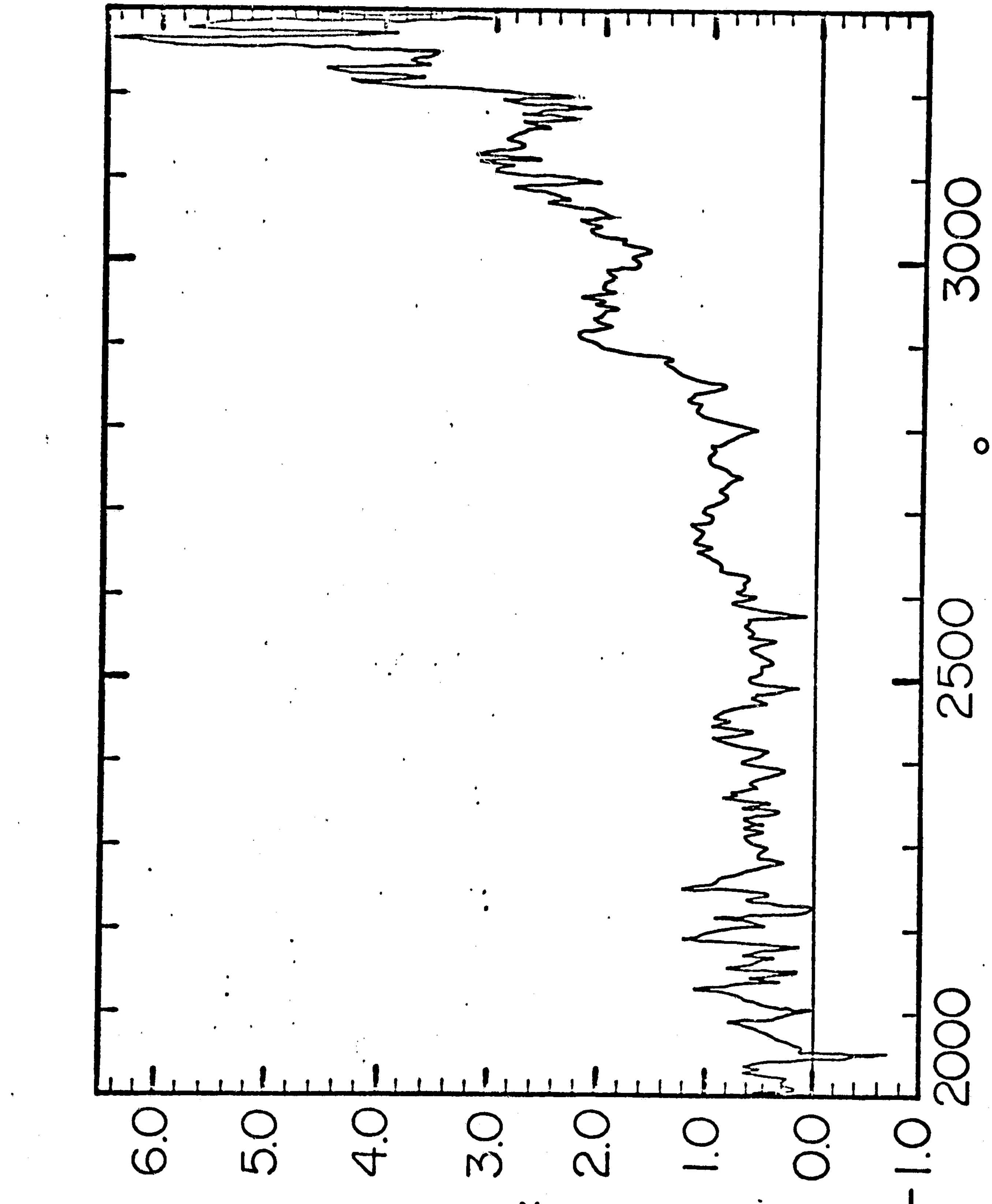
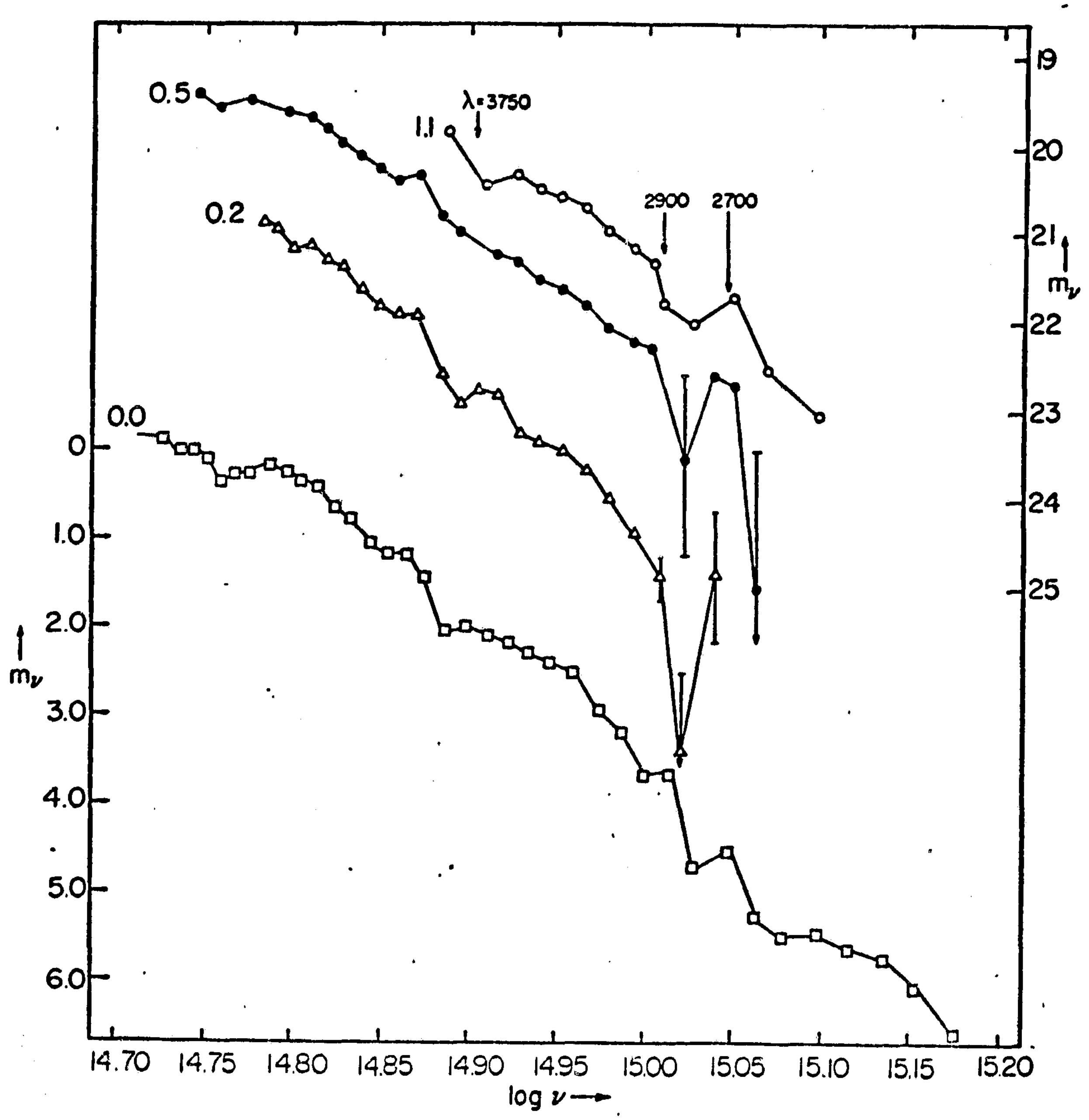


FIGURE 1.



0.5
1.1
λ=3750
0.2
2900
2700
0.0
0
1.0
2.0
3.0
4.0
5.0
6.0
m_ν
19
20
21
22
23
24
25
m_ν
14.70
14.75
14.80
14.85
14.90
14.95
15.00
15.05
15.10
15.15
15.20
log ν

FIGURE 2.